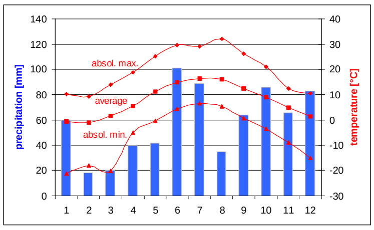
Case Study 15

Bayer Nordic Headquarters

office building, Lyngby
Denmark, Europe



MAP

climate		temperate	latitude, longitude		55.5°N, 12.3°E
HDD	**[18°]**	3 235 K·**d**	**summer solstice**	**[noon]**	57.3°
CDD	**[26°]**	0 K·**d**	**winter solstice**	**[noon]**	10.8°
altitude		20 m			

		jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	year
sunshine probability	**[%]**	33	31	44	35	44	38	44	48	42	42	34	21	38
sunshine hours	**[h]**	66	79	134	200	271	263	248	245	180	120	71	45	1922
sun altitude at noon	**[°]**	12.7	20.7	31.8	43.8	52.9	57.3	55.4	47.9	36.9	25.3	15.5	10.8	
temp., average	**[°C]**	-0.5	-1.0	1.7	5.6	11.3	15.0	16.4	16.2	12.5	9.1	4.8	1.5	7.8
temp., absol. max	**[°C]**	10.3	9.2	14.0	18.9	25.3	29.7	29.2	32.1	26.2	21.2	12.5	10.6	32.1
temp., absol. min	**[°C]**	-21.1	-18.0	-20.1	-4.9	-0.2	4.5	6.7	5.4	0.8	-3.4	-8.9	-15.0	-21.1
precipitation	**[mm]**	60	18	20	40	42	101	89	35	64	86	66	83	714
wind speed, average	**[m/s]**	5.0	4.4	4.8	4.5	4.1	3.8	3.9	3.5	4.4	4.5	4.5	4.9	4.4

table 1: Climatic data

figure 1: View of Bayer from west

figure 2: Wide angle interior view of the atrium

major issues

Nordic headquarters for Bayer, the German chemical and medical company, is located in Lyngby, Denmark. The building is a 4-storey, L-shaped building with an atrium following the long axis of both wings. The offices open to the atrium. Most of the offices are single occupancy with a few double occupancy offices.

The daylighting design uses bi-directional lighting. Daylight not only enters through the facade via two daylight windows (placed near the ceiling), but also through a glazed door opening to the atrium. Two additional windows on the facade are used as view glass. Finally, the corridors are both top and side lit.

Blinds are integrated between the windowpanes in the vision windows to optimise the offices for computer work. Glare-free lighting was the major design criterion for the offices because the occupants spend most of their time using computers. The blinds can be tilted, but they are not retractable.

The design intent was to reduce the use of electric lighting and increase daylighting. Presence detectors and light sensors control the electric light. This is done via the EIB system, an Intelligent Installation Bus from Siemens. However, the users can manually override the automatic control of the electric lighting.

site

The office building is located in Lyngby, north of Copenhagen. The urban environment is mostly commercial, 3- and 4-storey office buildings. The land is flat and there are no obstructions.

site data:			
land use	a mix of commercial and residence	**Footprint**	1 600 m^2
site area	5 332 m^2	**Footprint to site area ratio**	0.30

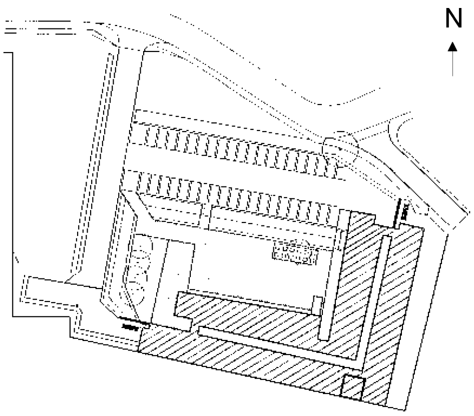


figure 3: Site plan (KHR Architects A/S)

figure 4: Overview of the site. Bayer is in the back of the picture

building

The building is L-shaped with an atrium in the centre of each wing. Approximately 150 people work in the building.

The architect's intention was to create a non-traditional building. The concept was two "streets" – the atrium – with a centre where the two wings meet (see figure 5). In a technological society, information exchange is important, and the atrium promotes a spirit of co-operation.

Oversized glazed doors join the offices with the atrium, creating a feeling of openness. This enhances circulation and enables easy and effective exchange of information.

building data:			
building construction period	1995-1996	**number of storeys**	4 (+ basement)
building owner	PFA (a pension fund)	**floor to floor height**	3.4 m
building costs	7 600 kr/m^2 (1 080 USD/m^2)	**floor to ceiling height**	2.7 m
architect	KHR A/S (Jan Søndergaard)	**number of occupants**	150
lighting consultant	KHR and Birch & Krogboe	**total energy use**	140 kWh/m^2
HVAC engineers	Birch & Krogboe A/S	**heating system**	central heating (water based)
total floor area	6 400 m^2	**cooling system**	no mechanical cooling
floor area of typical floor	1 600 m^2		

heat insulating properties, glazing types:			
wall	U-value: 0.3 W/m^{2}K	**windows**	double, low e
roof	U-value: 0.2 W/m^{2}K	**atrium**	double, low e
window	U-value: 2.1 W/m^{2}K		

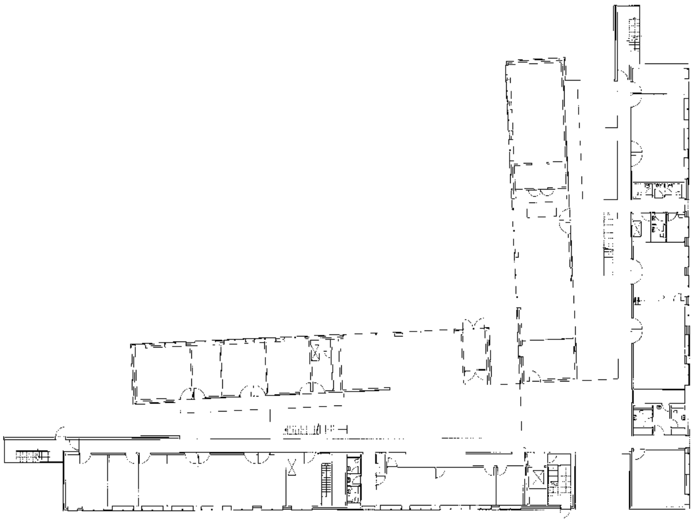


figure 5: Floor plan, ground floor (KHR Architects A/S)

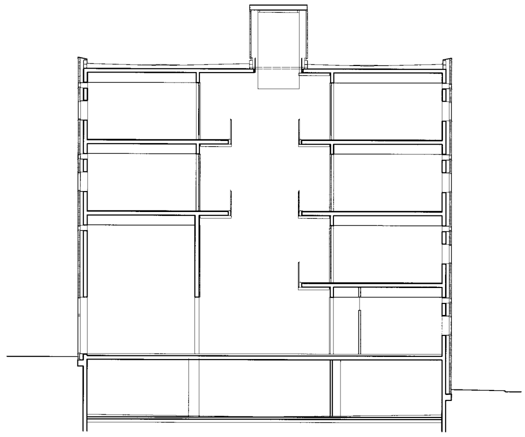


figure 6: Cross section (KHR Architects A/S)

figure 7: South facade

figure 8: Circulation area

daylighting strategies

The building is intended to optimise working conditions using integrated blinds and split windows (figures 7 and 9). The windows serve two functions: the lower part, vision windows, allows for a view of the outside, and the higher-placed windows are designed for daylighting. Electric lighting use is reduced by the use of daylight. The lights are controlled by the EIB.

To encourage daylighting, the offices have a depth of 5.2 metres.

The integrated blinds can be tilted, but not retracted from the window surface. The upper windows do not have blinds, so daylighting is not adversely affected. Privacy blinds are also integrated in the doors between the office and the atrium. The occupants can manually adjust all the blinds with an electric switch.

data for selected space:	
floor area of typical office	15.6 m^2
depth	5.2 m
width	3.0 m
material, colour, reflectance	
floor	carpet, grey, 25%
side walls	paint, white, 85%
rear wall	paint, white, 85%
ceiling	paint, white, 85%
window and glazing properties:	
window area (glazed + frame)	2.2 m^2
glazed area	1.8 m^2
window area to window wall ratio	0.27

floor to ceiling height		2.7 m
energy transmittance	blinds 45°/closed	25%/10%
door		paint, grey / glazed
shading device		blinds integrated between windowpanes
glazed area to window wall ratio		0.22
visible transmittance incl. shading device		28%/11%

figure 9: Interior view of an office, note the split windows

figure 10: Light sensor in the ceiling and presence detector in the corner

electric lighting

An Intelligent Installation Bus (EIB standard from Siemens) controls the building systems. Electric lighting is controlled in each room by presence detectors and light sensors via this EIB system. However, the users can manually override the control for electric lighting.

Fifteen minutes after occupancy, the electric lighting is automatically switched off. The lighting will be switched on when a person enters the office, if daylight is not sufficient to cover the lighting needs. During occupancy, the light sensor ensures that the electric lighting is dimmed depending on the daylight level. If the daylight itself is sufficient, the electric lighting is turned off.

When the occupants moved into the building, the office lighting was pre-set to 200 lux – the lighting level required by the Danish building regulations. Some occupants have had their level changed to 250 or 300 lux. For all working places an individual assessment was carried out with an optician to ensure the best working conditions for the employees.

During working hours users control the blinds manually. After the offices have been vacated the EIB signals the Building Management System, which closes the blinds and provides solar shading.

The bus system not only controls the lights, but also acts as a security system using the presence detectors. Finally, the bus system disables all non-critical electrical loads when a floor is completely unoccupied.

The luminaires use fluorescent lamps with high-frequency electronic ballasts. This increases efficiency and provides dimming capabilities. The fixtures are recessed into the ceiling.

office:	
lamp type	fluorescent lamps, Philips TLD 83
correlated colour temperature	3 000 K
luminaires used	Louis Poulsen
installed power density	9.3 W/m^2
control strategy	presence detectors + light sensors automatic dimming

atrium:	
lamp type	fluorescent lamps, Philips TLD 83
correlated colour temperature	3 000 K
luminaires used	designed by the architect
installed power density	8 W/m^2
control strategy	presence detectors + light sensors automatic on/off

monitoring, measured performance

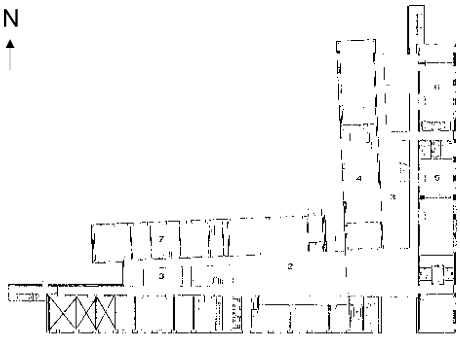


figure 11: Monitored offices – marked with X

specific features of the monitoring program

Three offices were selected for monitoring. The offices are located on the south edge of the building on the third floor. The results in this section are for the middle office.

In the middle office, three different lighting control strategies were tested. A different strategy was used for each of the three weeks. Testing occurred during the fall of 1998.

The strategies were:

- the presence detector and the light sensor were disabled. The occupants manually turned on and off the lights. This corresponds to a traditional system.
- the presence detector was enabled to turn off 15 minutes after occupancy. The occupant had to turn on the light manually (as in the first case, no dimming was used).
- both the presence detector and the light sensor were enabled to turn off 15 minutes after occupancy. As in case 2, the lights are turned on manually. The light sensor will regulate the electric lighting according to the daylight level.

Furthermore, a POE (post occupancy evaluation) study was performed on 34 occupants in October, 1997 and March, 1998.

monitoring:			
winter monitoring period	09.01.98 – 19.01.98	**thermal load analyses**	no
spring monitoring period	20.03.98 – 06.04.98	**POE studies**	2 waves
summer monitoring period	03.07.98 – 09.07.98	**experimental changes**	control of light

luxlevels on winter, spring and summer days

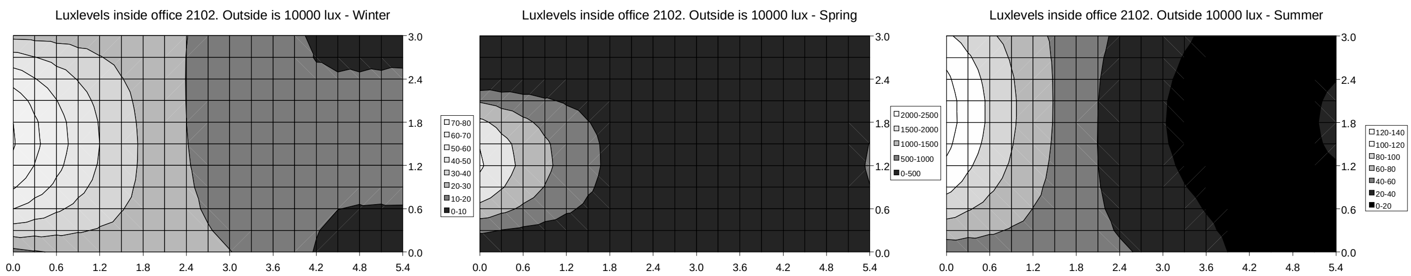


figure 12: Monitored illuminance distribution on a winter day (overcast sky), a spring day (clear sky) and a summer day (partly overcast day with a low illuminance level outside)

CIE sky

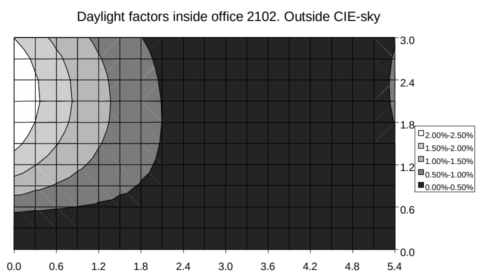


figure 13: Daylight factors

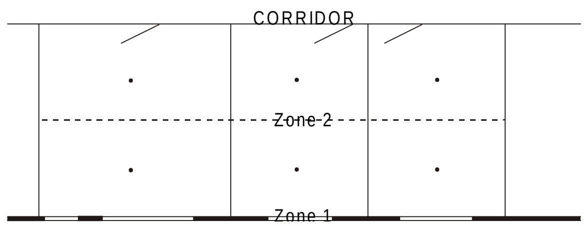
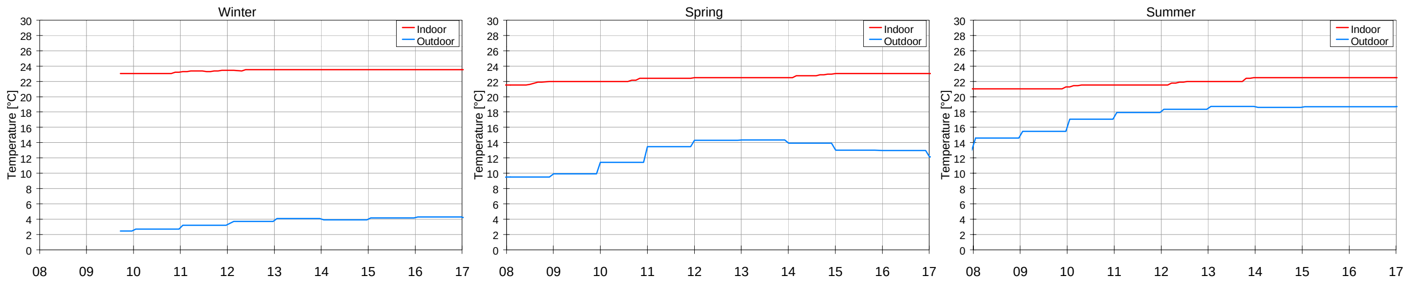


figure 14: Daylighting zones, position of sensors

indoor and outdoor temperatures

sunny day



cloudy day

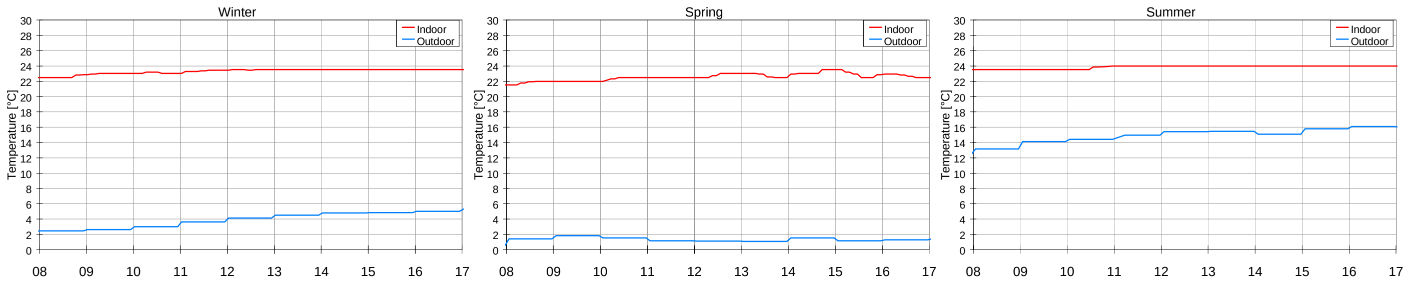


figure 15: Indoor and outdoor temperatures on a selected winter, spring, and summer day

The integrated blinds not only control glare, but also act as solar shading. The success of this element is seen from figure 15. The temperatures in the office did not exceed 24°C. One reason is that the measurements were carried out on days where the outdoor temperature did not exceed 19°C, due to non-extreme summer temperatures in 1998.

The occupants expressed that, during hot summer days in 1997, the top floor offices experienced some overheating. From this feedback, the atrium glazing was changed to a glazing with a lower solar energy transmittance. This solved the overheating issue.

winter, daylight and electric lighting energy use

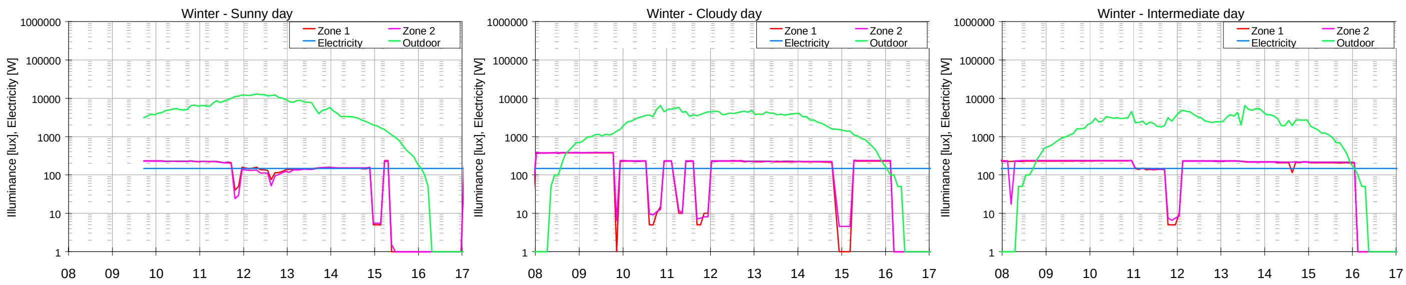


figure 16: Winter monitoring results

The measured data show that electric lighting is required during most days in winter. Due to low daylight factors, the daylight contribution cannot meet the total lighting requirements. Therefore daylighting does only a few times offset electrical lighting throughout the day during this week.

But energy is saved when compared to the situation with no sensors. Without presence sensors, electric lighting would have been on during the whole day with maximum electricity use. The presence detector did turn off the lights when the office was left during the day and during the evening at the end of the workday, which can be seen from the drop in illuminance level in the office during the day. Unfortunately the reading of the electricity use shows a constant value during the day, but this is due to a measuring fault.

spring, daylight and electric lighting energy use

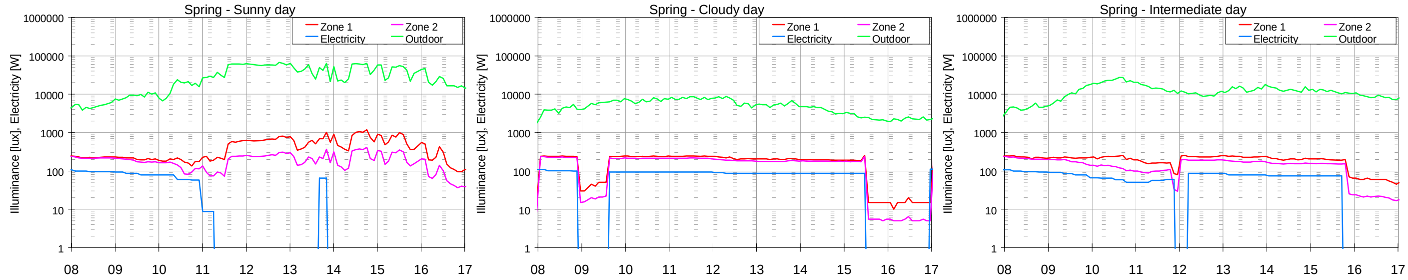


figure 17: Spring monitoring results

Measured springtime data show that electric lighting is not required all days. During cloudy days and intermediate days, the daylight contribution does not meet the total lighting requirements, and electric lighting was used.

Electricity consumption is zero between 09:00 and 10:00 on the cloudy day, even though the daylight contribution is low. The office was not occupied during this hour. If the employee in the office forgot to turn off the light before leaving for a meeting, the lights would have been on the whole day.

Most often, if an occupant leaves for a short time, the lights remain on. If the period is extended, the automatic control will ensure energy savings, turning off the light after 15 minutes.

On the sunny day the daylight contribution during the afternoon is sufficient to cover the lighting needs and the electric lighting was off.

summer, daylight and electric lighting energy use

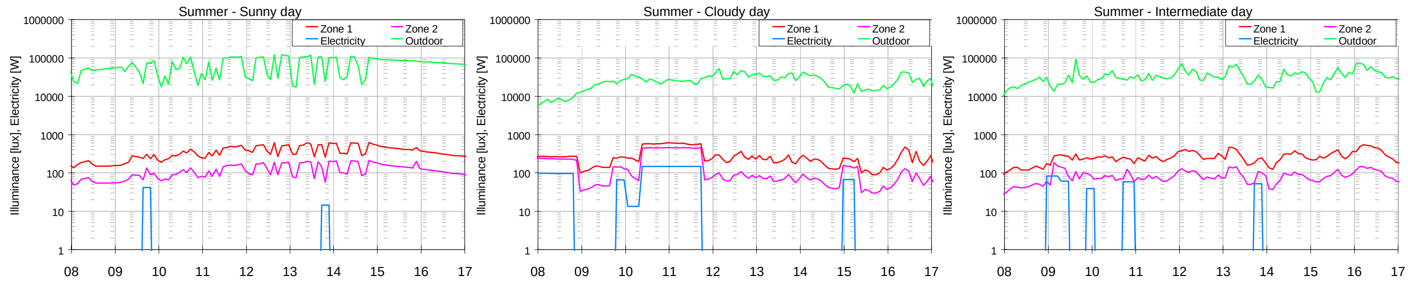


figure 18: Summer monitoring results

The measured summertime data show that the electric lighting can be off for long periods during all types of days because the daylight contribution is able to cover the needs for lighting.

Because the daylight contribution varies during the day, the light sensor adjusts to the appropriate light level, saving the maximum amount of energy. If the system had been a manual on/off system, most occupants would turn on the lighting in the morning when the daylight contribution is insufficient. Occupants tend to not turn off lights because of daylighting.

performance data

[kWh]	real performance 0-24 h	real performance 8-17 h	no daylight 8-17 h	relative savings 8-17 h
winter	23.5	21.5	27.8	23%
spring	9.2	7.8	27.2	71%
summer	2.7	2.3	30.5	92%

table 2: Electric lighting consumption [kWh/month] of the selected space during one month

[%]	zone 1 200 lux	zone 1 300 lux	zone 1 500 lux	zone 1 1000 lux	zone 2 200 lux	zone 2 300 lux	zone 2 500 lux	zone 2 1000 lux
winter	54	39	0	0	50	11	0	0
spring	52	39	9	1	23	7	0	0
summer	51	37	9	0	18	5	0	0

table 3: Percentages of time during one month between 08:00 and 17:00 when illuminance exceeds the bin illuminance value

Table 2 shows that the amount of electricity for lighting is reduced from winter to spring and from spring to summer. The savings are calculated compared to a system with no daylighting control. This calculation only is done during working hours. More than 90% savings were measured during the summer period.

Table 3 shows the percentage of time where the daylight illuminance inside the office exceeds different levels. Zone 1 is close to the window and has a higher percentage than zone 2, which is in the back of the office.

The required level of 200 lux was achieved over 50% of the time in zone 1. In zone 2, the level is lower. These values show that it is possible to cover a large part of the required lighting level using daylight, even if the non-retractable blinds blocks a part of the daylight when shading and glare protection is not needed. Retractable blinds would make it possible to save even more electricity.

In all offices it is possible to press a switch called “constant light.” The switch allows occupants to maintain 100% electric lighting and overrides automatic dimming. Fifteen minutes after occupancy the electric lighting is automatically switched off. When the office is occupied again, the control goes back to the original settings and the presence detector and light sensor will control the electric lighting. If the “constant light” switch is used often, the savings will be smaller than those reported.

performance evaluation of different control strategies

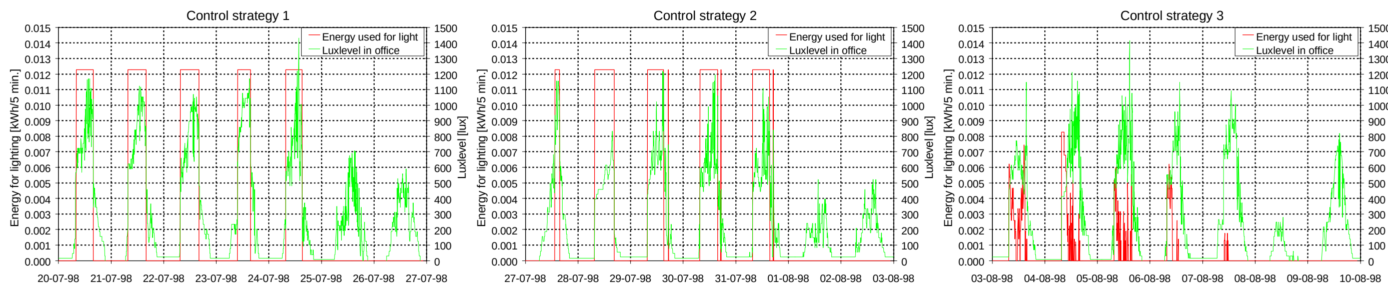


figure 19: Comparison of different control strategies for electric lighting

Figure 19 shows energy use for electric lighting and the measured illuminance level for the three different control strategies. The illuminance levels are wall levels, using readings from the light sensor.

The control strategies are described on page 5.

Control strategy no. 1: The figure shows that the light had been turned on in the morning and off again in the evening when the occupant left. When the occupant left the office during the day, the light was not turned off.

Control strategy no. 2: The occupant still turned on the light in the morning, but when the occupant leaves the office during the afternoon (Wednesday, Thursday and Friday) the light is automatically turned off. The occupant turns it on again when returning to the office.

Comparing the two control strategies, it is clear that turning the light off automatically will save electricity for lighting.

Control strategy no. 3: The figure shows that electricity used for lighting is changing throughout the day. Compared to the other strategies, this strategy saves a considerable amount of energy.

figure 20: During sunny days the integrated blinds can cause glare

figure 21: The blinds can cause veiling reflections on the screens

The POE was carried out on the second and third floor in offices facing north and south. The first wave was carried out in October 1997 using the automatic lighting control. Electric lighting was turned on and off automatically according to presence and daylight availability. In December, the control strategy on the second floor was changed to a manual on and automatic off system. The third floor was kept as a reference. In March 1998, the second wave was carried out.

A total of 34 people participated in the POE, but not all of them answered the questionnaire twice (both waves). The number of people surveyed was insufficient to make strong recommendations for future buildings. Generally, there were no significant changes in the answers from the two waves, and the results can therefore only be seen as guidelines.

In the questionnaire, occupants were asked how satisfied they were with different aspects of their workplace. For each of the aspects they could chose between very satisfied, satisfied, indifferent, dissatisfied or very dissatisfied. The answers can be seen in figure 22 below.

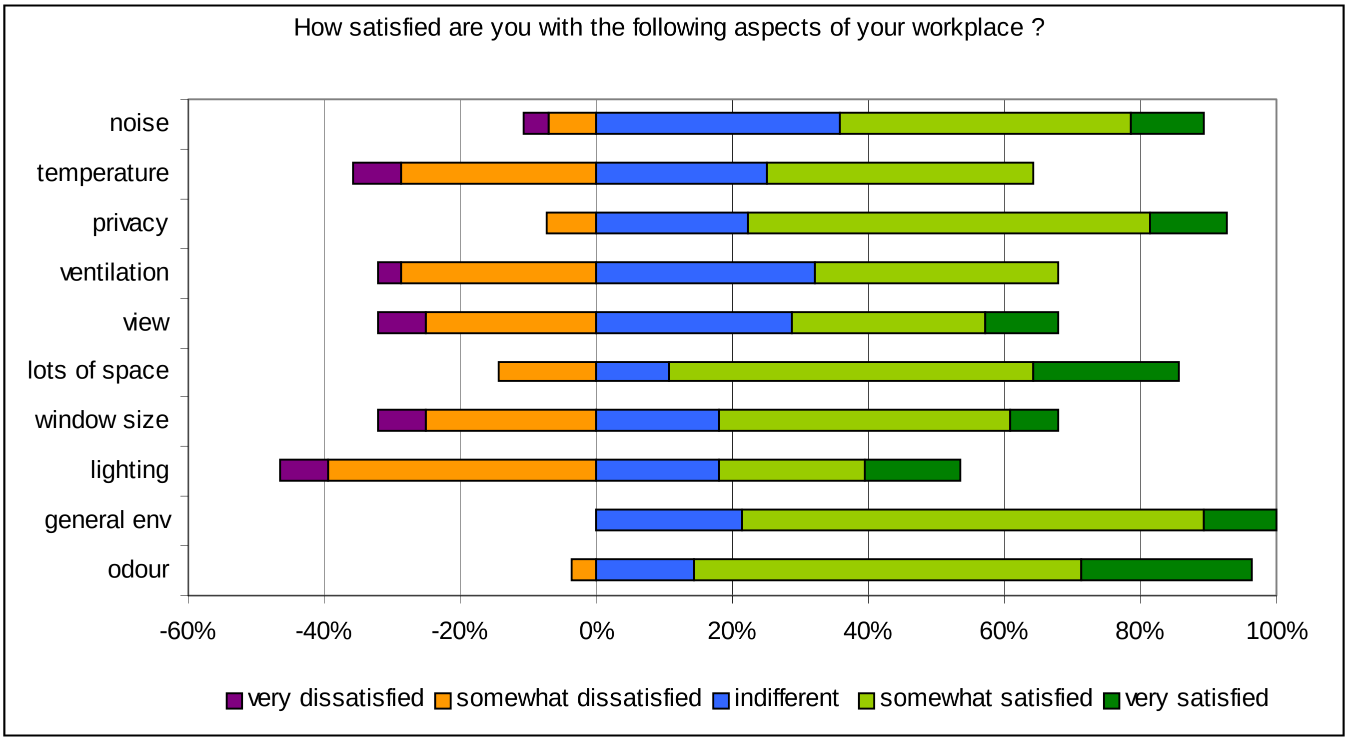


figure 22: Satisfaction regarding different aspects of the workplace (answers from both waves included)

Figure 22 shows that none of the occupants involved in the POE were dissatisfied with the general environment and that only a few occupants were dissatisfied with privacy, amount of space and odour. This corresponds to replies on what occupants especially liked about the building. Typical answers were: an ‘open’ and light building, easy communication, the atmosphere, a light and ‘friendly’ building, the big and open hall, the good light effect from the skylight, the open structure and nice and modern building.

The figure also shows that 39% were dissatisfied with the lighting, and 7% were very dissatisfied. This aspect has been further investigated, and the results are shown in figure 23.

Thirty-six percent were dissatisfied or very dissatisfied with the temperature. The reason for the extreme building temperatures was that the summer of 1997 was very hot. After changing the windows in the upper part of the atrium to windows with a lower energy transmittance, the overheating problem was solved. Because of daylighting, electric lighting was used a minimal amount of the time, resulting in lower office temperatures. Even though the occupants were dissatisfied, the temperatures were lower than if the lights were generating heat.

People were also asked what they especially disliked. Typical answers were: automatic light control, the blinds are not retractable, the colours (grey and black), the blinds do not function as intended (they did not move synchronously and some had a manufacturing fault), lack of summertime ventilation, and too hot – especially on third floor. This can also be seen in figure 22.

A specific question was asked about the satisfaction of the automatic lighting control. They had five different possibilities: very satisfied, satisfied, indifferent, dissatisfied or very dissatisfied. Twenty-five percent were satisfied or very satisfied, 20% were indifferent and the majority (55%) was dissatisfied or very dissatisfied.

The occupants who were dissatisfied or very dissatisfied were asked what they did not like about the automatic control. The answers can be seen in figure 23 below.

The majority of the complaints regarding the control were related to the “automatic off” control. Some of this dissatisfaction was due to lack of understanding of the system. The occupants found it annoying that they had to get up and turn on the light again using the “constant light” switch when the light was turned off automatically. They thought the presence detector had too low a sensitivity, which shows that they do not understand the integration of the controls. They did not understand that the electric lighting was turned off because the amount of light coming from daylight was sufficient. After explaining the control system for the occupants this type of complaints was almost eliminated.

The second most common complaint was about the dimming of the light. The occupants found the dimming annoying. Talking to the occupants before analysing the questionnaires, they did not mention the dimming as a problem. One of the reasons for these complaints might be the time required to get used to the system. In the previous building no automatic lighting controls were used.

The number of persons satisfied and very satisfied increased from the first to the second questionnaire, both for the control group and the group who experienced the change of lighting system. This supports the explanation that it takes time to get used to a new control system. The increase was higher for the “experimental group” than for the “control group,” indicating that the problems caused by the automatic control of the lighting had a negative influence on the rating of the system.

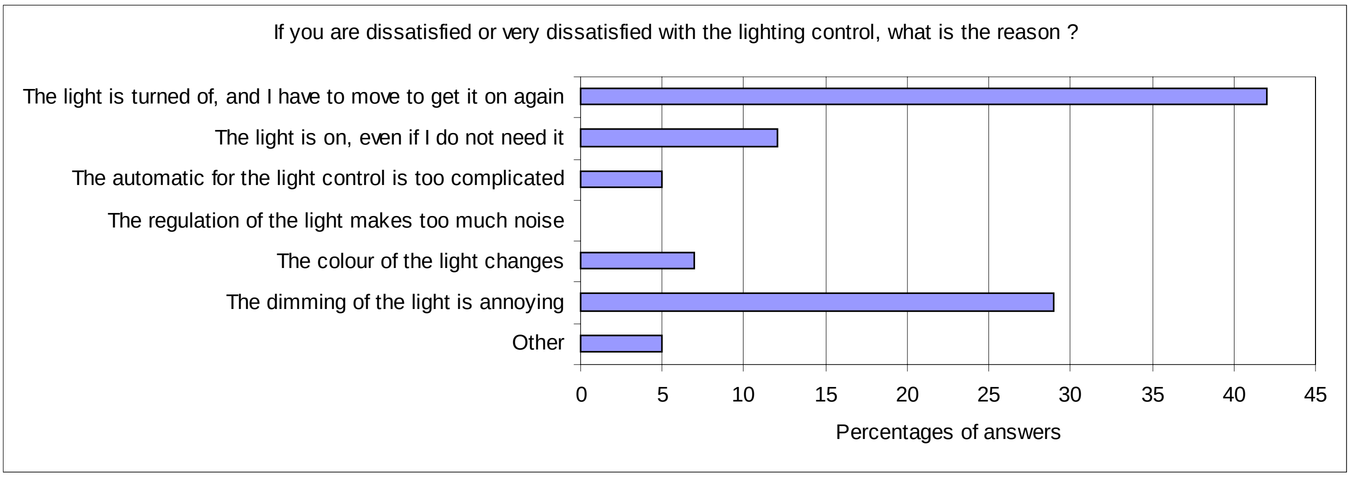


figure 23: Overview of complaints regarding the automatic control of the lighting. More than one answer was allowed

The occupants were also asked if they were satisfied with the solar shading. They could again choose between very satisfied, satisfied, indifferent, dissatisfied or very dissatisfied to describe their feelings about the shading. Fifty-three percent were satisfied or very satisfied, 6% were indifferent and 41% were dissatisfied or very dissatisfied. The occupants who were dissatisfied or very dissatisfied were asked what they did not like about the solar shading. The answers can be seen in figure 24.

One-third of the complaints were related to obstruction of the view. Quite a few of the occupants (31%) did not like the immovable shading. The net effect was perceived by some as "a prison."

Some bright summer days the blinds can cause glare if not closed fully. Even though this problem did not appear in the formal questionnaire, it surfaced during informal questioning of the occupants.

From the surveys and informal discussions with the occupants, two other problems were noted with the blinds that were seen as serious. One problem was that the blinds in the two vision windows did not move synchronously when the switch was pressed. Furthermore, the location of the switch was inconvenient in some offices. The occupants therefore found the control of the blind difficult.

The second problem was that the blinds could not be adjusted during the wintertime. This was due to a fault during the manufacturing process. The windows had been manufactured under wrong temperature and pressure conditions. After changing one third of the windows, the problem was solved.

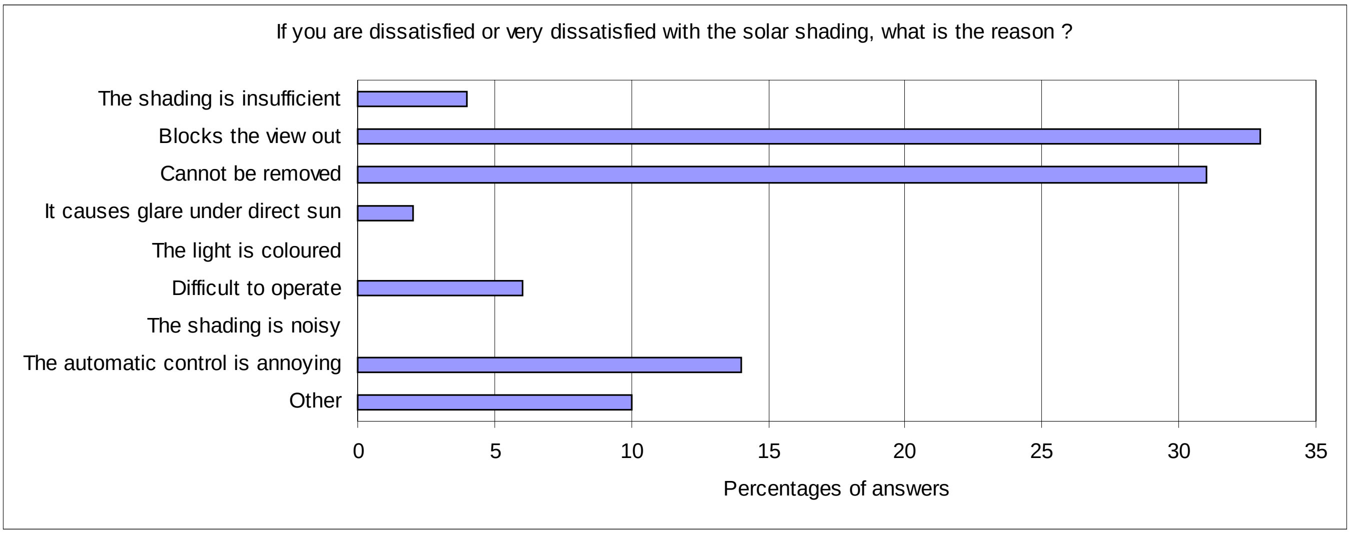


figure 24: Overview of complaints regarding the solar shading. More that one answer was allowed

discussion of daylight strategy and monitoring results

figure 25: Wide angle view of window area

figure 26: Wide angle view of office

The non-retractable integrated blinds were chosen to optimise computer work, and the POE results showed that they were functioning well. Less than half of the surveyed group had experienced disturbing reflections on the computer screen.

Fifty-three percent of the people who answered the questionnaire were satisfied or very satisfied with the blinds as solar shading. Under clear sky conditions, 51% used the shading often and 22% used it sometimes. Only 27% said that they only occasionally or never used the shading. The majority of the people, who did not adjust the blinds, have north oriented offices.

The occupants who were not satisfied with the shading generally complained about the fact that the shading blocked the view. Furthermore, they disliked the fact that the shading cannot be removed when not needed. Retractable blinds could solve these problems.

Selecting blinds with a lower reflection could solve the problem that the blinds themselves can cause glare. This should be taken into consideration when selecting solar shading.

Solar shading placed outside is more effective than shading placed between the windowpanes. If changing the windowpanes in the atrium roof could not have solved the overheating problem during summertime, the best solution would have been to add external shading to the offices. This might not have been accepted for architectural reasons.

The low daylight factors seen in figure 13 can be explained by the fact that the integrated blinds are not retractable. During periods with overcast sky, electric lighting is turned on to meet lighting needs. If the blinds had been retractable, the amount of daylight coming to the offices could be increased on overcast days without glare problems.

The monitoring of daylight and electric lighting started with a test to see the influence of the light coming from the atrium via the oversized glazed door into the offices. The amount was small compared to the amount from the windows. But psychologically, it had a big effect. The occupants liked the large doors because it opened the building and made it "light and friendly." The small amount of light from another source balances the sunlight through the external windows.

The presence detectors and the light sensors are important for the energy strategy of the building. Lack of proper user education caused some dissatisfaction with the sensors when the building was new. When the lights were turned off due to a high daylight level, some occupants thought that the presence detectors were out of order – they did not understand why the lights were turned off even if the office was occupied. Many occupants were more satisfied with the system after they understood the control strategies.

The occupancy questionnaire showed it takes time to get used to new technologies. The number of people who were dissatisfied with the automatic control of the light was lower the second time the questionnaire was administered.

The main conclusions from the monitoring and post occupancy evaluation are:

- It is possible to save a considerable amount of electricity using presence detectors and light sensors.
- The non-retractable blinds are well functioning as glare protection, but they are disliked by the occupants because they block too much of the view.
- Bi-directional light is important for balance.
- External shading is better for solar control.

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